Efficiency of traditional maize storage and control methods in rural grain granaries: a case study from Senegal

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Summary

Maize storage and pest control method as practiced in traditional clay granaries in the Kédougou region in eastern Senegal were evaluated under rural conditions during two successive years. Three storage modes, i.e. maize cobs, winnowed and non-winnowed maize grains, were tested in seven granaries where the insecticidal plants Hyptis spicigera *or* H. suaveolens *were either incorporated in the store structure or deposited as layers intermittently with maize. At the beginning of the storage period, all granaries were artificially infested with 7 pairs* Tribolium castaneum *and* Sitophilus zeamais. *No damage, losses or live insects were observed during 7 months of storage when maize cobs were placed between layers of* H. spicigera. *Compared with the control, incorporation of insecticidal plants within the granary bottom had no significant effect on the damage and loss level irrespective of the storage mode. Non-winnowed maize always suffered less damage and losses than the winnowed variant. In all granaries depredation, insect abundance and moisture content were highest toward the end of storage period between June and July.*

Résumé

Efficacité de méthodes traditionnelles de stockage et de traitement du maïs en greniers paysans - Etude de cas au Sénégal

Le stockage et les méthodes de traitement du maïs tels que pratiqués dans les greniers traditionnels à Kédougou dans l'Est du Sénégal ont été suivis pendant deux années successives. Trois modes de stockage – épis de maïs – grains de maïs vannés et non vannés ont été testés dans sept greniers où les plantes insecticides Hyptis spicigera *ou* H. suaveolens *sont soit incorporées dans la charpente du grenier soit déposées intermittement (en sandwich) avec des couches de maïs. Tous les greniers ont été artificiellement infestés au début du stockage par 7 couples de* Tribolium castaneum *et* Sitophilus zeamais. *Il n'a été observé ni dégât, ni perte ou d'insectes vivants durant sept mois de stockage quand les épis de maïs sont en sandwich dans des couches de* H. spicigera. *Par rapport au témoin, l'incorporation des plantes au fond des greniers n'a pas eu d'effet significatif sur les dégâts et pertes indépendamment du mode de stockage. Le maïs non vanné a toujours été moins attaqué que celui vanné. Dans tous les greniers infestés, le niveau des populations d'insectes et l'humidité ont été plus élevés à la fin de la période de stockage entre juin et juillet.*

Introduction

Maize has become well established as a staple food in the human diet in eastern and southern Senegal. However, limited work has been devoted to the evaluation of locally developed post-harvest methods for this cereal crop. Thus in 2012, a diagnostic survey involving 330 maize producers was conducted to investigate the main storage types and methods within these geographical areas (6). The study revealed that the producer's financial resources and the availability of local materials were the major drivers for the adoption of storage

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types. At the same time, insects were found to be the principal threat for stored maize with losses ranging from 18% for shelled maize, to 20 % for stored cobs and 27% for stored and shelled cobs.

In another study in Senegal, S*itotroga cerealella* (Olivier) (Lepidoptera: Gelechiidae) and *Ephestia cautella* (Walker) (Lepidoptera: Pyralidae) proved to be the principal insect pests of traditionally stored sorghum causing a serious threat to on-farm stored seed materials (18). Infestation by *S. cerealella* was observed to start already in the field, but during storage moths were never detected beyond 30 cm depth within bulk deposited grains after threshing (19). By contrast, in large scale state-owned food security reserves, Guèye (5) found mainly *Corcyra cephalonica* (Stainton) (Lepidoptera: Pyralidae), *Rhyzopertha dominica* (Fab.) (Coleoptera: Bostrichidae), *Tribolium castaneum* (Herbst) and *T. confusum* Jacquelin du Val (Coleoptera: Tenebrionidae) from millet samples collected in the twelve main regions of the country.

In Senegal the commonest pest control method in stored commodities remains the use of synthetic pesticides, but some farmers have opted for the use of native plants to protect their stores against insects. These bio-pesticides are considered to be efficient since their action persists for about 5 months and even throughout the dry season (7).

Applications methods of these plant-based insecticides, however, can differ from one region to another. In eastern Senegal it was observed that whole plants of the bush mint species *Hyptis suaveolens* (L.) Poiteau and *H. spicigera* Lamarck (Lamiaceae) are either directly integrated in the bottom of storage structures or deposited on the floor of granaries. In addition, within these traditional devices maize is stored in various modes.

In the present study the efficiency of such practices is evaluated in relation to dynamics of maize pest infestations. To this end, field work was carried out for two successive storage periods in 2011 and 2012 and occurrence of insects, their proliferation, damage and losses was followed up in maize stored as cobs, winnowed and non-winnowed grains.

Material and methods

Context of the study

The research was conducted in the Tomboronkoto and Sékoto villages situated in the Kédougou region in eastern Senegal (12°29’20”N 12°17’26”W). This region is located within the eastern, more humid, fringe of Senegal, which has a sub-Guinean climate. The mean maximum temperature was 34.8 °C while the minimum 21.7 °C, with highest levels recorded in April (40 °C) and lowest in December (17 °C). The rainy season generally starts in May and ends in October-November, with a mean annual rainfall of 1200 mm.

Plant material

The two plants used to control insects in traditional stores, namely *Hyptis spicigera* and *H. suaveolens*, grow abundantly in the surroundings of villages. Based on own observations over two successive years, both plant species undergo their vegetative cycle during the rainy season and become truly fragrant toward December-January. They are usually dry out in February except in inland-valleys where they remain green until March.

Construction of granaries – The experiment was carried out using self-constructed granaries except for one grain store (G5). Whereas the body of such a granary consists of bamboo rods its bottom is made of thick branches over which a uniform and thick layer of insecticidal plants is deposited. According to local farmers, layers of *Hyptis spicigera* build an effective barrier that prevents insects from penetrating into the stores. To create an additional isolation, a layer of 5 to 10 cm moistened clay is laid upon the plants leaving them concealed between the ground and the granary floor. Upon use, all storage openings were sealed with cow dung. Store G5 differed because it was built on the roof of a mud hut. Thus, a construction similar to the one described above was erected on the flat hut roof but this time with the inclusion of H. suaveolens in the bottom layer alike the process above.

Experiment setup

The experiment arrangement is depicted in figure 1. The trial was conducted in full compliance with practices in use within the concerned geographical areas. Granaries G1, G2 and G5 were situated in Sékoto whereas G3, G4, G6 and G7 in Tomboronkoto. Granaries G6 and G7 were built in the second year to allow additionally a comparison with methods applied in other areas of Kédougou region, namely the storage of maize cobs intermittently sandwiched with layers of *H. spicigera*. The granaries in Sékoto had a storage capacity of 4.4, 9.6 and 15.5 m3 whereas those in Tomboronkoto 2.4, 3.2, 4.5 and 3.5 m3 respectively. Samples were taken at a time interval ranging from 45 to 60 days between February 2011 and July

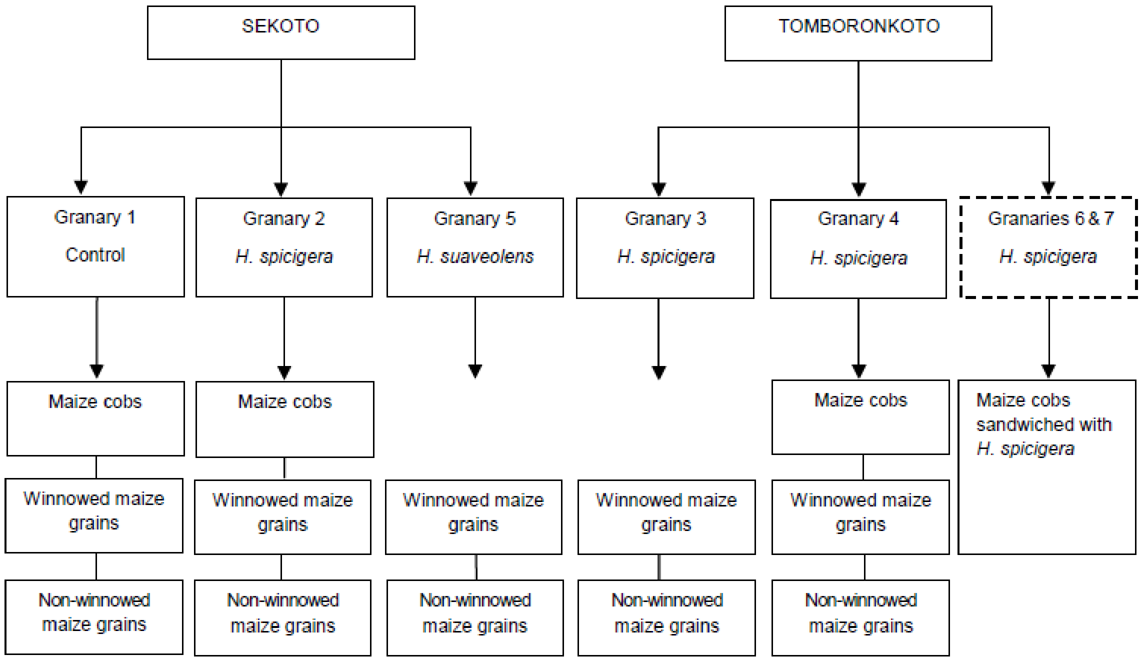

Figure 1: Experimental setup deployed at Sékoto and Tomboronkoto.

2012, in a time span covering two dry seasons (November to May). Prior to the storage freshly harvested maize is customarily sun-dried on raised racks, its actual conservation in granaries usually starts from November.

To strengthen and / or ensure the presence of storage pests, granaries were artificially infested with *Tribolium castaneum* and *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae), two major pests of stored maize in tropical and subtropical regions (12, 2). On 30th March 2011 and 15th February 2012 respectively, seven pairs of each pest species were introduced in every single granary to test the action of the insecticidal plants and/or the storage method. During the entire duration of the study granaries were not treated with synthetic insecticide.

Sampling

Sampling was carried out according to the method by AFNOR (1) where the number of bags from which samples are collected is determined by the size of the lot. For winnowed and non-winnowed maize, a probing pipe was used to reach the various levels of bags stacked in the granaries. A composite 1 kg sample was collected from a number of sub-samples taken from six to ten randomly chosen sacks which were pooled together. For the cobs, specimen samples were collected at various strata either within sacks or from strings made of cobs bond together by their husks and attached on the granary roof or hanging on sticks placed across the granary. Counts of number of individuals from each insect species were performed on-site. Maize samples were then transported to the laboratory where damage and loss measurements were made within a week of collection.

Parameters used for evaluation

Grain and cob moisture content were measured on-site with a Dickey-John handheld Mini Gac Plus ® tester (Churchill Industries, Minneapolis, USA). Values used for insect pests represent number of individuals per kg. Percent grain damage and weight losses were calculated according to the formula by Pantenius (16) as follows:

$$Damage = \frac{Number\ of\ damaged\ grains}{Total\ number\ of\ grains}\ x\ 100$$

where A is the total number of grains; B, the number of attacked/damaged grains; C, the number of healthy grains; D, the weight of attacked/damaged grains; and E, the weight of healthy grains.

Statistical analysis

Statistical analysis was performed using GenStat Discovery V4.0. Data were first subjected to a variance analysis. A test of homogeneity of variance followed when probability values were below 5% i.e. when the hypothesis of equity among means was rejected. The Student-Newman-Keuls test was used to check for homogeneity of variance. For the evaluation of cob data, a factorial design with incomplete blocks was specifically applied since data from some granaries were lacking on certain dates for this storage mode due to early consumption by some farmers.

Results

Significant differences (P< 0.01) between granaries, sampling dates and the three tested storage modes (cobs, winnowed and non-winnowed grains) were observed.

No damages or losses at all were observed in G6 and G7 where maize cobs were stored in strata alternating with thick layers of H. spicigera. Since congruently no insects were recorded within these granaries related data were left out from the ANOVA analysis.

The size of the granaries was not significantly correlated to damage or loss values. The highest damage was found on winnowed maize in G4 (16.49%) and G1 (14.93%) respectively. Damage on cobs was significantly higher in the control granary G1 (11.13%) and below one percent in G2. Lowest damage levels were recorded in G4 on non-winnowed maize with values reaching only 6.76% at maximum. Regardless of the storage mode, lowermost losses were found in G2 with 0.33, 2.99 and 6.48% for cobs, non-winnowed and winnowed maize respectively (Table 1).

Differences in weight losses were similarly observed between granaries and storage modes. Peak loss values for cobs (2.33%) were recorded in G1 whereas for winnowed (3.10%) and non-winnowed grains 1.64% they were found in G4. Overall, for any given granary, non-winnowed grains always showed lower grain weight losses than winnowed ones.

A comprehensive analysis of the damage level and sampling dates showed that for the same periods, damages were statistically more severe in 2011 than in 2012. Significant differences were also found between the three storage modes. The highest damage on cobs (6.60%) was observed during March 2011, whereas winnowed (27.91%) and non-winnowed maize (11.09%) showed highest damage levels during July of the same year. Surprisingly, the damage on winnowed maize was always at least twice the value of the non-winnowed variant (Table 2).

Table 2

Homogeneity test of means (ANOVA) of percent damage and losses on maize Cobs, winnowed (W) and non-winnowed (N) grains for granaries G1 to G5

	Damages (%)			Losses (%)		
	Cobs	W	N	Cobs	W	N
G1	11.13a	14.93b	3.53c	2.33a	2.58b	0.97c
G2	0.33b	6.48d	2.99cd	0.09c	1.04d	0.82c
G3	-	11.72bc	3.10c	-	2.10c	0.63d
G4	3.62c	16.49a	6.76a	0.96b	3.10a	1.64a
G5	-	10.32bc	4.50b	-	1.94c	1.19b

Monitoring of insect populations showed that, except for granaries G6 and G7 which remained insect-free, both introduced pest species had established in all stores and were recovered throughout the study (Table 3). Overall, pest insects were more abundant during the first than the second year. In addition to the three introduced beetles species, the rice moth *Corcyra cephalonomia* (Stainton) (Lepidoptera: Pyralidae), the lesser grain borer *Rhyzopertha dominica* (Fabricius) (Coleoptera: Bostrichidae) and the grain beetle Cryptolestes sp. (Coleoptera: Cucujidae) were only sporadically recovered.

Because of heavy termite attack, granary G1 had to be built again in July 2011 and restocked. Regardless of the sampling period and storage mode, *T. castaneum* was usually more numerous than *S. zeamais*. Winnowed maize was generally more infested than the non-winnowed variant. Cobs and winnowed maize were equally attacked in G1 and G4 but only very little in G2. Overall, insects proliferated less in G2 and G3 than in other stores. In some granaries peak populations either of *T. castaneum* or *S. zeamais* were recorded in July of the first year and reached similar densities both on winnowed and non-winnowed maize.

During 2011 moisture values remained generally low and permitted good storage conditions regardless of the storage mode. Fluctuations remained within a range of 3 to 4% lower than the maximum record of 14% measured in August on cobs in the control G1 (Table 4).

In the second year, except for G1 and G5, these

Table 3

Seasonal insect fluctuation (number of insects/kg) in maize granaries G1, G2 & G5 in Sékoto and G3 & G4 in Tomboronkoto between February 2011 and July 2012

	Damages (%)			Losses (%)		
	Cobs	W	N	Cobs	W	N
Feb. 11	4.29b	11.63bc	-	1.76a	2.36bcd	0.72d
March	6.60a	18.07b	5.75c	1.49ab	2.58bc	1.01c
May	4.07bc	17.89b	8.28b	1.81a	2.88ab	1.22c
July	3.31cd	27.91a	11.09a	0.89d	3.35a	2.07a
Aug.	3.55cd	7.47d	2.27e	1.25c	1.91d	1.03c
Dec.	0.57g	3.94d	0.53f	1.32abc	0.62e	0.14e
March 12	1.95f	11.0bc	2.24e	1.49ab	2.04cd	0.52d
June	2.52e	8.82bcd	3.49d	1.67a	1.87d	1.20c
July Aug.	0.27g	8.46bcd	3.83d	1.55ab	1.76d	1.56b

Table 4

Humidity fluctuation in maize granaries G1, G2 & G5 in Sékoto and G3 & G4 in Tomboronkoto between February and July 2012

	Granary 1			Granary 2			Granary 3		Granary 4			Granary 5	
	C	W	N	C	W	N	W	N	C	W	N	N	W
Feb.	8.9	8.6	*	9.8	8.6	*	9.5	*	8.9	8.5	*	10.3	*
March	9.3	8.9	8.2	10.4	9.5	8.8	9.8	9.2	9.3	9.2	8.2	10.7	10.2
May	11.3	10.0	9.2	10.9	10.2	9.6	10.2	9.3	10.7	10.2	9.6	11.2	10.6
July	12.3	11.5	11.5	12.2	11.5	11.5	10.6	10.2	11.7	11.5	11.2	11.8	11.2
Aug.	14.0	11.5	11.2	_	12.7	12.3	12.0	_	12.6	12.6	13.0	_	_
Dec.	9.6	9.2	*	10.5	11.4	*	12.2	*	11.9	11.8	*	10.2	*
March	10.3	9.8	9.7	11.8	11.2	10.8	12.9	13.7	11.2	10.8	10.4	10.5	10.0
June	11.5	11.2	10.9	16.3	_	15.1	18.6	15.9	17.8	16.4	15.9	_	_
July	12.7	12.2	11.8	_	_	_	17.3	_	_	_	_	_	_

values were consistently higher especially from June on where moisture increased up to 18.6% on winnowed maize in G3.

Discussion

The present study revealed clear tendencies resulting from traditional post-harvest practices as applied by farmers in the Kédougou region. The most effective method proved to be the storage of maize in granaries with intermittent layers of *H. spicigera*, which resulted in full protection of the commodity against any insect damage. This however, was not achieved when the same species or *H. suaveolens* were incorporated in the storage structure. It is therefore thought that the mode of action of both Hyptis species is due to the release of bioactive molecules contained in the essential oil. To date, numerous studies determined the active components or effectiveness of these plants against various storage pests (20, 13, 14). According to Noudjou et al. (15), the toxicity of *H. spicigera* is strongly influenced by its α-pinene content (39%). However, many studies have demonstrated that biopesticides based on essential oils rapidly decrease in effectiveness, due to volatile molecules being massively released already during the first days after application (11). Hence, the insecticidal effects of *H. spicigera* may last only shortly in granaries. On the other hand, farmers believe in a repulsive action of these two plants which justifies their incorporation into the storage structure to deter any intruding pests. Since in the here presented study storage pests were directly released into the granaries presumed repulsive effect could not be tested. When insecticidal plants were incorporated between the clay layers of the storage structure, diffusion of insecticidal volatiles may have slowed down, limiting the direct know-down effect while still acting as a deterrent against new colonizers. Whether the use of Hyptis in layers affects the gustative quality of maize was not mentioned by farmers. This possible consequence should be assessed in further research.

In the present study, the granary size had no significant effect on the extent of damage and losses. By contrast, the storage mode played an important role as evidenced by a consistently stronger insect attack on winnowed than on non-winnowed maize. Thus, except for July 2011, loss rates of non-winnowed maize barely exceeded maxima of 1%. This result is in agreement with laboratory studies where damage and losses on stored maize grains remained below 5% and 1% respectively when *S. zeamais* were exposed to powdered maize cob particles of 1.4 and 0.4 mm diameter, similar to non-winnowed grains at doses greater than or equal to 2.4% (w/w) (7). Furthermore, increasing the amount of powdered cobs did not have a lethal effect on *S. zeamais* adults, but lead to a considerable delay in juvenile emergence strongly affected levels of the F1 generation. As a result, weevils did not penetrate into deeper grain layers and caused only little damage. The presence of the primary pest *S. zeamais* may have created conducive conditions for the proliferation of *T. castaneum* who often outnumbered weevil numbers. This confirms findings by Bekon and Fleurat-Lessard (3) who, besides losses demonstrated a positive correlation between the amount of frass generated by *T. castaneum* and the damage caused by the primary pest when storing cereals over 40 days. A similar positive relationship between *S. zeamais* and *P. truncatus* has been demonstrated in earlier studies storing maize (22). By contrast, *S. zeamais* was shown to outcompete *S. cerealella* under identical conditions (10). In the here described experiment it was observed that *T. castaneum* was more abundant than *S. zeamais*.

The response of *T. castaneum* and *S. zeamais* to diverse plants exhibiting insecticidal properties has been the subject of multiple studies. Liu et Ho (11) observed that *S. zeamais* was more sensitive than *T. castaneum* to contact with the oil of *Evodia rutaecarpa* (Hook f. and Thomas) (Rutaceae), but more tolerant to fumigation with the same product. However, in another experiment, LD_{50} and LD_{95} values revealed a similar sensitivity of both species to applications of essential oil of *Elletaria cardamomum* (L.) Maton (Zingiberaceae). Furthermore *T. castaneum*, whose larval stages were more resistant than adults, proved to be twice as tolerant as *S. zeamais* when fumigated with this essential oil (9). It was demonstrated that naturally synthetized products such as Spinosad can also be highly effective, since a dose of already 1 ppm in stored wheat or maize provides a total control against *T. castaneum* and *S. zeamais* under rural conditions (8).

Initial levels of insect infestation play a crucial role for maintaining post-harvest quality of crops. Infestation in maize contamination can already start in the field. This could explain the high damages levels observed in G1. This treatment already showed high levels in March whilst at the same time pest attacks in G2 were almost nil, despite the introduction of equal numbers of *S. zeamais* and *T. castaneum* in both granaries. Similarly, there is evidence that field infestations of *S. cerealella* on rice are highly correlated with the abundance of the moth populations in stored rice (21). Significant differences in the proliferation level of insects between the two study years are probably due to varying abiotic factors. Such natural fluctuations commonly occur when stores are infested with the larger grain borer *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) and are expressed in varying infestation levels from one year to the other (4).

In the here reported trial grain moisture remained generally below 14% up till May, safeguarding the maize. However, between June and July of the second year, high levels of moisture content were reached subsequent to the onset of the rainy season between late May and early June. High humidity probably favored attacks by termites and *C. cephalonica* in G1. Similar to the here presented results, Ratnadass & Sauphanor (17) also registered an increase of grain maize moisture in traditional stores following the rise of relative humidity at the beginning of the rainy season. Among all tested stores, G5 was the only granary hut built with hard-clay. At the same time it showed little moisture fluctuations in the stored grains, which implies a comparatively better protection against humidity by this material. This property may be important, especially since along with moisture uptake, the stored maize tended to become more vulnerable to pest attacks as evidenced by peak populations of both *T. castaneum* and *S. zeamais* measured in most granaries with high moisture levels.

Conclusion

The present study allowed assessing the efficiency of traditional maize post-harvest methods and storage systems as practiced by farmers of the Kédougou region in Senegal. The storage of maize cobs using a sandwich method with *Hyptis spicigera* proved to be fully effective against storage pests, and was able to preserve maize for up to 7 months. However, the limited data obtained for this treatment calls for further investigations to confirm its efficacy. The storage of non-winnowed maize grains offered a substantial degree of protection against insect infestations. By contrast, the traditional practice of incorporating insecticidal plants in layers of mud within the storage structure did not reduce the development of pests introduced into the granaries.

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